THE NICKEL BULLETIN

A MONTHLY SUMMARY OF CURRENT INFORMATION

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ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

NICKEL

Ammonia Pressure Leaching Process for Extraction of Nickel and Other Metals

F. A. FORWARD and V. N. MACKIW: 'Chemistry of the Ammonia Pressure Process for Leaching Nickel, Copper and Cobalt from Sherritt Gordon Sulphide Concentrates.' *Jnl. of Metals*, 1955, vol. 7, Mar.; *Trans. Amer. Inst. Mining and Metallurgical Engineers*, 1955, vol. 203, pp. 457–63; T.P. 3951 BD.

The paper relates to the laboratory and pilot-plant studies carried out by Sherritt Gordon Mines, Ltd., Metallurgical Research Division, in developing the ammonia pressure leach process for extraction of copper, nickel, cobalt and sulphur from high-grade nickel concentrate produced from the ores of Lynn Lake.

In this process the reactions in the leaching stage, which are heterogeneous in character, are such that oxygen dissolves in an ammoniacal leach liquor and there reacts with the solid sulphides, to give oxidized products including (*a*) nickel, cobalt, and copper ammines, (*b*) sulphate, thiosulphate, polythionate and sulphamate ions, and (*c*) hydrated ferric oxide.

The rate of leaching is controlled by temperature, by the ammonia concentration in the leach liquor, by the oxygen pressure, and by amount of agitation. Temperature and ammonia concentration are the most important factors, although adequate oxygen and sufficient agitation must be ensured. The leaching operation is regulated to produce a pregnant liquor having a content of thiosulphate and polythionate sufficient to react with the copper present in the subsequent boiling stage and to produce an iron oxide residue low in adsorbed nickel.

The pregnant liquor is boiled to produce 15 per cent. aqua and to lower unbound ammonia to the point at which thiosulphate and polythionates decompose by reaction with copper ions to produce copper sulphide. In a second copper-removal stage, the temperature of the boiled solution is raised to over 250°F. (120°C.), to accelerate the decomposition of thiosulphate and to precipitate copper sulphide to a stage at which the copper content of the solution is only 0·03 g. per litre. The copper is finally reduced to 0·001 g. per litre by addition of a measured stoichiometric amount of hydrogen sulphide.

The final copper-free solution, containing about 45 g./L. of nickel, 0·8 g./L. of cobalt, 0·001 g./L. of copper, in addition to sulphur as sulphate and sulphamate in an amount of 80–90 g./L., is in suitable condition for subsequent operations associated with precipitation of nickel.

The authors give a detailed account of the chemistry of the process, with flow diagrams and a considerable amount of experimental data.

Solubility of Oxygen in Molten Nickel and Iron-Nickel Alloys

H. A. WRIEDT and J. CHIPMAN: 'Solubility of Oxygen in Liquid Nickel and Iron-Nickel Alloys.' *Jnl. of Metals*, 1955, vol. 7, Mar.; *Trans. Amer. Inst. Mining and Metallurgical Engineers*, 1955, vol. 203, pp. 477–9.

During the past twenty years a considerable background has been built up with regard to the chemical

Table I

Summary of Solubility Data
(Interpolated)

Temperature °C.	Nickel	20% Iron Alloy	50% Iron Alloy	Iron
1450	0·28	—	0·10	—
1500	0·40	—	0·12	—
1550	0·58	0·13	0·15	0·18
1600	0·82	0·16	0·19	0·23
1650	1·15	0·20	0·23	0·28
1700	1·59	—	—	0·34

behaviour of oxygen in liquid iron, but little information has been developed on oxygen in liquid nickel or on the effect of nickel, as an alloying element, on the behaviour of oxygen in liquid steel. The work reported in this paper was planned to provide data on these aspects.

Nickel. Samples were taken from a bath of molten electrolytic nickel held under an air atmosphere in a magnesia-lined 30-lb. induction furnace. Saturation of the melt with oxygen was effected partly by addition of chemically pure black nickel oxide and partly by the air atmosphere. Samples were taken only when there was a clearly visible oxide phase present.

Iron-Nickel Alloys. The technique was similar to that employed with nickel, with the following exception: a pre-purified nitrogen atmosphere was used, in order to avoid uncontrolled atmospheric oxidation, which would have removed iron preferentially from the alloys. Ferric oxide was used as the source of oxygen. Electrolytic iron additions were made during the run, to obtain varying compositions.

Results of individual determinations at various temperatures, together with other experimental details, are given in the report, and the summary of solubility data is given on the previous page interpolated from all the information obtained in the tests.

Transition Structure in Evaporated Nickel Films

G. I. FINCH, K. P. SINHA and A. GOSWAMI: 'The Transition Structure of Nickel.' *Jnl. Applied Physics*, 1955, vol. 26, Feb., pp. 250–1.

In the range of temperature between 300° and 370°C. nickel exhibits anomalies in physical properties such as specific heat, thermal coefficients of expansion and electrical resistance, and rigidity. These anomalies cannot be fully accounted for by the magnetic transformation associated with the Curie point, which occurs at 358°C.

In certain ferromagnetic alloys changes in crystal structure occur near the Curie point, but no such phase transformation has been reported for nickel within that region. Normally the stable structure of nickel, both below and above the Curie range, is face-centred cubic, but the existence of hexagonal (close-packed) structure has also been reported by some investigators.

No body-centred-cubic form has until now been observed in evaporated films of nickel, but the authors of the present note report that they have found, by electron diffraction, that under appropriate conditions a body-centred-cubic nickel can be formed in thin films and that on heating above 400°C. this changes to the normal face-centred-cubic structure. (The nickel films examined were thermally deposited from a nickel-coated hot tungsten wire in a high vacuum, at various temperatures, onto heated substrates such as cleavage faces of rock salt and mica, or on glass. The specimens were cooled rapidly in vacuo, to room temperature.)

None of the electron-diffraction patterns obtained in these experiments showed any trace of a preferred crystal orientation, and from this absence of any sign of epitaxy it is concluded that the film growth was unaffected by the nature of the substrate. It would appear that formation of the b.c.c. phase was primarily dependent on the temperature of the substrate: the structure of films deposited on substrates heated to 300°–340°C. was found to be b.c.c., but that of films deposited on substrates above or below that range was f.c.c. Rate and duration of evaporation affected the ease with which the b.c.c. structure could be observed, but the authors consider that this is a secondary effect, for which thickness of film and crystal size were responsible, the metastable b.c.c. structure being most easily frozen in thin films and with small crystal size. It is pointed out that at this stage of the investigation it is impossible to say whether traces of foreign atoms, such as tungsten, may play an important rôle in stimulating formation of the metastable b.c.c. phase. Microcrystals of tungsten (b.c.c.) might, it is believed, act as potential centres of crystallization of the new phase, and enhance nucleation rate, i.e., they may act as embryos in the matrix of the b.c.c. phase.

Photometric Determination of Nickel by Means of Ethylenediaminetetra-Acetic Acid

W. NIELSCH and G. BÖLTZ: 'A New Method of Photometric Determination of Nickel by Means of Ethylenediaminetetra-Acetic Acid.'
Analytica Chimica Acta, 1954, vol. 11, Oct., pp. 367–75.

The authors show that, by working at a pH of 4·55–6·82, it is possible to determine high concentrations of nickel photometrically by means of ethylenediaminetetra-acetic acid. Absorption curves obtained for this complex are found to be closely reproducible.

Large amounts of ammonium salts have an interfering influence, and should be avoided. The Lambert-Beer law is followed for concentrations of nickel from 40 to 5,000 mg. per 100 ml., and it is claimed that the procedure is particularly suitable for determination of nickel in high-nickel alloys. Full details of analytical technique are given.

Analysis of Thin Films of Nickel and Stainless Steel

T. N. RHODIN: 'Chemical Analysis of Thin Films by X-Ray Emission Spectroscopy.'
Analytical Chemistry, 1955, vol. 27, Feb., p. 316.
Abstract of paper to Pittsburgh Conference on Analytical Chemistry, Feb.-Mar., 1955.

The report deals with application of X-ray emission spectroscopy to the quantitative analysis of thin evaporated films of iron, nickel, chromium, and austenitic nickel-chromium stainless steel, deposited on a polyester backing. Oxide films associated with the passivity of three types of nickel-chromium stainless steels were also studied.

Comparison of the metallic compositional data obtained by X-ray methods for metal and oxide films 300 A. in thickness or less to those obtained independently by microcolorimetric methods indicate excellent agreement.

ELECTRODEPOSITION AND OTHER COATING METHODS

Influence of the Physical Condition and the Processing of the Basis Metal in Electroplating

A. E. R. WESTMANN and F. A. MOHRNHEIM: 'The Influence of the Physical Metallurgy and Mechanical Processing of the Basic Metal on Electroplating. Part I. Critical Review of the Literature.'
Plating, 1955, vol. 42, Feb., pp. 154–8, 195.
Report issued under the aegis of A.E.S. Research Project No. 14.

The literature review now published was made as a preliminary to research by the American Electroplaters' Society. Initially the experimental work is to be limited to a study of steel as the basis metal and nickel or nickel+chromium as the coatings. The work done will aim at determining the influence of the properties of the steel prior to the cleaning operation, as affecting the final qualities of the cleaned and plated products.

The manufacture of a nickel- or nickel+chromium-plated article may be considered as comprising the following stages:

(*a*) steel manufacture (to strip, sheet, rod, etc.),

(*b*) forming (punching, drawing, etc.),

(*c*) grinding,

(*d*) polishing,

(*e*) buffing,

(*f*) cleaning,

(*g*) plating.

The project under consideration is concerned with the effects introduced in stages (*a*) to (*d*), and the literature (up to June, 1953) is discussed in appropriate sequence. Manufacture of steel strip is taken as typical.

The study of the literature reveals a need for a more metallurgical approach to the problem and for more detailed experimental work: it is considered that fruitful results might be obtained by investigation of the effects of the microgeometry of the basis metal.

The *bibliography* of literature on which the survey is based numbers 75 items.

See also continuation, *ibid.*, Mar., pp. 281–6.

This instalment (Part I, Second Section), is concerned mainly with a critical review of the literature relating to the effect of commercial polishing of steel, on the properties of the electroplated coatings. Particular attention is given to investigations in which an attempt has been made to correlate variations in an industrial polishing procedure with the corrosion-resisting properties of electrodeposited nickel coatings on steel. The term 'polishing' is used in the review in the current industrial sense of the term accepted in the U.S.A., and is equivalent to 'bobbing' in English terminology. ('Buffing', known in England as 'mopping', in which a cloth wheel and only a very fine abrasive, dispersed in a binder, is used, will be treated in a later section.) The *bibliography* associated with this section of the review numbers about 60 references.

Inhibited Acids in Nickel-Plating Baths

J. W. CARROLL: 'Inhibited Acids in Plating Cycles.'
Metal Finishing, 1955, vol. 53, Mar., pp. 60–3.

There is some prejudice, in the plating industry, against the use of inhibitors in acid pickling baths, due to a belief that such additions adversely affect adhesion and the final appearance of the plating. The author of this article presents experimental data to disprove this contention, and urges that the following advantages can be gained by the use of inhibited acids: reduction in labour costs and cost of materials, reduction in evolution of hydrogen, reduction in amount of hydrogen adsorbed by the metal, improved appearance of the coating, improved rinsing properties, reduction of the human-error factor, permissible extension in time or temperature of pickling, safer stripping.

As a support to the recommendation that wider use should be made of inhibited acids, the author gives results of tests made to determine the influence of such additions on adhesion of nickel coatings. Six different inhibitors were tested, representing the main types commercially employed. The data obtained show that while incorrectly chosen inhibitors can adversely affect adhesion, others are without effect. Adequate rinsing is a particularly important factor. In a second series of tests, inhibitors in varying proportion were added to a bright-nickel bath, and the influence on operation of the solution was evaluated. These tests indicated that certain inhibitors, even when added in substantial quantities, have no harmful effect on operation of the bath, that with inhibitors which have any deleterious influence the effects can be greatly reduced, or totally eliminated, by adequate rinsing between pickling and plating, and that any effects which might arise from build-up of inhibitor in the plating bath will be eliminated in the periodic carbon and hydrogen-peroxide treatment. Finally, a series of tests was run to ascertain the effect of inhibitors on the appearance of bright-nickel coatings: these, like the other experiments, emphasized the importance of correct choice of inhibitor, and good rinsing, but confirmed that, provided that such correct conditions are observed, inhibited acids can be satisfactorily used. The article closes with four typical preparatory cycles showing the incorporation of inhibited-acid treatment in preparation for nickel, cadmium, and zinc plating.

Plating of Bumper Guards: Use of Nickel Strike in Place of Copper

M. WEINBERG and A. LAKE: 'Bumper Guards.'
Plating, 1955, vol. 42, Feb., pp. 144–6, 159, 179.

The writers describe practice which has proved successful in plating of bumper guards in the shops of the Parker-Wolverine Division of the Udylite Corporation.

The importance of a suitable grade of steel, in correct physical condition, is emphasized, and precautions which should be observed in forming and drawing, polishing, racking, size and placing of anodes, etc., are reviewed. Automatic machine polishing is preferred, both on account of the uniformity of the finish obtained and also on grounds of economy.

The cleaning cycle is as follows:—

Cathodic cleaning; rinsing; anodic cleaning; rinsing; acid dipping (25% muriatic acid); rinsing; anodic cleaning; rinsing; acid dipping; rinsing. The sequence of two anodic cleanings, with an acid dip between them, has been found more effective than one longer anodic cleaning followed by an acid dip.

Following the final acid dip and rinse, the parts are placed in a nickel-strike solution, the composition of which is:

	Oz./gal.
Nickel Sulphate	16
Nickel Chloride	16
Boric Acid	2·5
Acid	0·3 normal or higher

Current density 15–20 amp./sq. ft.: 1–3 minutes; room temperature.

The nickel strike has been used in the Parker-Wolverine plant since early 1948, and is stated to be preferable to a copper strike. A markedly better bond is obtained between the final bright nickel and the steel base (a feature of great importance on bumper guards); fewer tanks are required; the process is easier to control than copper-striking; it is cheaper to operate; the use of cyanides is eliminated; no heating is required, and, in normal conditions, exhaust ventilation is unnecessary.

After the nickel-strike treatment the work is placed immediately in the bright-nickel bath, with the work cathodic. The bright-nickel baths are continuously filtered, and the cathode rods are agitated, to accelerate deposition and rate of brightening. After nickel plating the parts are twice rinsed, and finally chromium-plated and doubly rinsed.

Analysis of Effluents from Plating Baths

E. J. SERFASS and R. F. MURACA: 'Analytical Determination of Trace Constituents in Metal Finishing Effluents. VII. The Colorimetric Determination of Manganese in Effluents.' *Plating*, 1955, vol. 42, Feb., pp. 147–8.

The method described was developed as a result of co-operative work by the American Electroplaters' Society (Research Project No. 2) and the Ohio River Valley Water Sanitation Commission. It involves treatment with hot concentrated acids, to remove organic materials and chlorides, and subsequent oxidation of the manganese to permanganate, with potassium periodate. The intensity of the permanganate colour, together with interfering colorations, is measured. A blank, made by bleaching the permanganate colour of a similarly treated sample, corrects for interfering colorations.

The procedure described, suitable for determination of the manganese content of effluents in the range 5–50 p.p.m., has been found to yield satisfactory results in the presence of as much as 5,000 p.p.m. of each of twenty-four cations in simultaneous admixture, as well as in the presence of large amounts of organic materials.

Electroless Nickel Plating

G. GUTZEIT: 'Electroplated versus Electroless Nickel.' *Metal Finishing*, 1955, vol. 53, Mar., pp. 128–9.

Comments on review of potential usefulness of the electroless process, published *ibid.*, Feb., p. 51; see *Nickel Bulletin*, 1955, vol. 28, No. 3, p. 45.

NON-FERROUS ALLOYS

Chromium-Rich Chromium-Nickel Alloys: Constitutional Study

C. STEIN and N. J. GRANT: 'Chromium-Rich Portion of the Chromium-Nickel Phase Diagram.' *Jnl. of Metals*, 1955, vol. 7, Jan., Sect. 2; *Trans. Amer. Inst. Mining and Metallurgical Engineers*, vol. 203, pp. 127–34; T.P. 3882 E.

The authors open with a succinct review of conclusions drawn from the major investigations on the constitution of chromium-nickel alloys, and point out that conflicting evidence has been advanced with regard to the chromium-rich portion of the system.

The experimental work described in this paper was carried out on alloys over the percentage composition range 50 chromium, 50 nickel to 90 chromium, 10 nickel: very pure materials were used, of which full analyses are given. The investigation was based mainly on measurements of electrical resistivity, substantiated in part by metallographic examination, and more fully by lineal analysis and work with diffusion couples. A diagram arrived at as a result of the observations made, and supported by data from other recent sources, is shown.

A comparison of this diagram with that determined by WISE and EASH (see *Metals Handbook*, 1948 edition) shows several important differences. In addition to the eutectic reaction determined by Wise and Eash at 1343°C., the present work indicates that a eutectoid reaction occurs at 1215°C., between a high-temperature chromium phase, β, and two solid solutions, α chromium and γ nickel.

The solvus lines of the chromium-rich alloys determined in both these investigations have similar shapes, but resistivity measurements and lineal analysis made by the present authors show that, in general, the solubility of nickel in chromium is higher than that reported in the earlier work.

The transition in pure chromium, from the α to the β phase, was determined by BLOOM and GRANT as being at 1840°C. (*Trans. Amer. Inst. Min. Met. Eng.*, 1951, vol. 191, p. 1009), and a comparison of the phase diagram proposed by those authors and that

resulting from the present work shows that the two are very similar. Based on resistivity measurements and on lineal analysis, however, it is suggested that the eutectoid composition of 65 per cent. chromium reported from the X-ray diffraction work of BLOOM and GRANT be adjusted to 68 per cent. chromium.

The maximum solubility of nickel in chromium, as now determined, decreases rapidly between 1215° and 1100°C., at which temperatures the values are, respectively, 25 and 18 per cent. nickel. Below 1100°C. the solubility of nickel in chromium changes but little.

The thermal-analysis work of JENKINS, BUCKNALL, AUSTIN and MELLOR, on alloys rich in chromium, showed anomalous breaks in the curves at 950°C. on cooling and at 1100°C. on heating (*Jnl. Iron and Steel Inst.*, 1937, vol. 136, p. 193). This temperature range is approximately the one determined by the present authors resistivity measurements as the critical range, in which heating or cooling rates in excess of 1·5°C. per minute no longer result in attainment of equilibrium conditions. This critical heating and cooling rate probably occurs due to the very sharp change in the solubility of nickel in the α chromium in this temperature region (see above).

Influence of Nickel on Isothermal Transformations in Aluminium Bronzes

R. HAYNES: 'Some Observations on Isothermal Transformations of Eutectoid Aluminium Bronzes below their M_S Temperatures.'
Jnl. Inst. Metals, 1954-55, vol. 83, Mar., pp. 357-8: Advance Copy 1604.

Microstructural changes occurring during transformation in three aluminium bronzes below their M_S temperatures were studied. The observations made suggest that isothermal formation of martensite occurs, and that both martensite and the phase from which it forms may transform to eutectoid. Small additions of nickel, e.g., 3 per cent., were found to depress the M_S temperature and increase the rate of transformation.

Nickel-containing Ternary Alloys of Uranium

G. B. BROOK, G. I. WILLIAMS and E. M. SMITH: 'Pseudo-Binary Phase Sections between Laves Phases in Ternary Alloys of Uranium.' *Jnl. Inst. Metals*, 1954-55, vol. 83, Feb., pp. 271-6; Advance Copy 1595.

The phase boundaries, at 700° and 900°C., were determined in the pseudo-binary systems UMn_2-UNi_2, UFe_2-UNi_2 and UCo_2-UNi_2.

Titanium-Nickel-Oxygen System

W. ROSTOKER: 'Selected Isothermal Sections in the Titanium-Rich Corners of the Systems Ti-Fe-O, Ti-Cr-O and Ti-Ni-O.' *Jnl. of Metals*, 1955, vol. 7, Jan., Sect. 2; *Trans. Amer. Inst. Mining and Metallurgical Engineers*, vol. 203, pp. 113-16; T.P. 3863 E.

Single isothermal sections have been constructed for the titanium-rich corners of the systems Ti-Fe-O (1000°C.), Ti-Cr-O (1000°C.) and Ti-Ni-O (900°C.), with a view to locating the shape and disposition of the ternary intermediate-phase fields for the compounds isomorphous with Fe_3W_3C. Phase relationships were studied by both X-ray diffraction and metallographic methods. The report is well illustrated by photomicrographs, and by detailed diagrams of the isothermal sections at the temperatures indicated.

Effect of Temperature on Mechanical Properties of Nickel-Copper Alloys

See abstract on p. 92.

Elastic Constants and Thermal-Expansion Characteristics of Piping Materials

See abstract on p. 92.

Enthalpy and Specific Heat of High-Nickel Alloys and Stainless Steels

See abstract on p. 91.

Hard Facing with Nickel-base Alloys

See abstract on p. 97.

NICKEL-IRON ALLOYS

Calibration of Nickel-Iron and Other Length Standards

B. L. PAGE: 'Calibration of Meter Line Standards at the National Bureau of Standards.'
Jnl. of Research, Nat. Bur. Standards, 1955, vol. 54, Jan., pp. 1-14; R.P. 2559.

The paper reports results of intercomparisons of the total lengths of several meter bars, and of calibration of the sub-intervals of some of these bars for the past twenty years. The work described not only provided information on the degree of stability of the standards, but also made possible assessment of the precision with which such measurements can be repeated. The results are critically analysed, and comments are made as to the precautions necessary in precision comparison of line standards of length. The bars examined were of platinum-iridium (four units), Invar (two units), 42 per cent. nickel steel, Fix Invar, and stainless steel of straight high-chromium type.

Solubility of Oxygen in Molten Iron-Nickel Alloys

See abstract on p. 83.

Nickel in Iron and Steel: Textbook

A. M. HALL: 'Nickel in Iron and Steel.' Published for the Engineering Foundation, by *John Wiley & Sons, Inc.*, New York; *Chapman & Hall, Ltd.*, London; 1954, xii+595 pp. Price 80/-.

The many users of the pre-war volumes in the Alloys of Iron series are welcoming resumption of publication and the resulting extension of subject coverage. The most recent accession, concerned with nickel as an alloying element in irons and steels, is complementary to '*The Alloys of Iron and Nickel, Part I*' (1938), which dealt with the properties of high-purity iron-nickel alloys and with special-purpose alloys of relatively high nickel content.

The Alloys of Iron Monograph series is planned to provide metallurgists and engineers with concise, but comprehensive, summaries of available data on alloy steels and cast irons, as reported in the technical literature of the world. In 1942, when publication of '*Nickel in Iron and Steel*' had to be suspended, a large amount of work had already been done in reviewing the literature to that date, and although later developments have necessitated much revision, the preparatory work strengthens the text as now issued. The literature reviewed, at the earlier date and during revision, numbers about 2,000 items, and after elimination of papers which were important at the earlier stage, but are now of only historical interest, 800 important items still remain as the basis of this up-to-date survey of the influence of nickel as an alloying element in ferrous materials. The *bibliography* ranges from 1860 to early 1953.

The introductory chapter of the book, which deals briefly with nickel-containing minerals, the occurrence of nickel-bearing ores, and extraction and refining of nickel, is followed by chapters summarizing the present state of knowledge on melting and working of nickel-alloy steels, heat-treatment used for the various types, structural and transformational characteristics, physical and mechanical properties (at normal and at elevated temperatures), corrosion-resisting qualities, welding technique, and miscellaneous fabricating operations. A separate chapter is devoted to the composition and properties of cast nickel-alloy steels, and the volume closes with three chapters on the constitution and structure of nickel-alloy cast irons, manufacturing processes used for their production, and the mechanical and physical properties obtainable by alloying with nickel (used alone or in conjunction with other elements).

As in the other monographs in the series, the individual author named has been responsible for selection and evaluation of the data, for arrangement of subject matter, and for style of presentation, but the value of the work is much enhanced by the fact that the draft was submitted for comment to members of the Iron Alloys Committee, and other representative individuals in academic and industrial circles in the U.S.A. The book thus embodies an extensive range of experience and opinion on all aspects of the subject covered. It will rank high, for many years, as a work of reference.

Solubility of Oxygen in Molten Nickel and Iron-Nickel Alloys

See abstract on p. 83.

Temper-Brittleness of Pressure-Vessel Steels: Summary of Information

L. D. JAFFE: 'Temper-Brittleness of Pressure-Vessel Steels.' *Welding Jnl.*, 1955, vol. 34, Mar., pp. 141S-50S.

This report, prepared under the sponsorship of the Materials Division of the Pressure Vessel Research Committee of the Welding Research Council, comprises a correlated review of existing information. Reference to original literature is given in a *bibliography* of 177 items.

The scope and arrangement of the review are indicated in the skeleton of contents given below:

Introduction: (nature of temper-brittleness; characteristics of the fracture, etc., with good photomicrographs).

Thermal Cycles Leading to Temper-Brittleness (and remedial treatments).

Effect of Composition (corrective influence of molybdenum; effects of chromium, manganese, nickel, vanadium, phosphorus, sulphur, silicon, aluminium, boron, arsenic, titanium, cobalt, tin, lead, copper, antimony; influence of deoxidation practice).

Effect of Prior Heat-Treatment (tempered martensitic *vs.* tempered bainitic structures; lessened susceptibility in steels of pearlitic and ferritic structure. Effect of austenitic grain size and of hardness).

Temper-Brittleness in Welding (paucity of information; embrittlement in nickel-molybdenum-vanadium steel weld metal during stress-relieving).

Temper-Brittleness in Pressure Vessels (review of likely behaviour, in pressure-vessel service, of plain carbon and low-alloy steels, including precipitation-hardening types. No failure of conventional pressure vessel steel has yet been ascribed to temper-brittleness, but it is considered possible that such failure may have gone unrecognized in some cases).

Prevention and Cure (avoidance of temperature conditions likely to induce temper-brittleness; use of base metal and weld metal having low transition temperatures; re-heat-treatment for restoration of embrittled material).

Theories of Temper-Brittleness (four major theories merit consideration: (1) precipitation of iron-carbide particles or films, probably sub-microscopic in size, at austenite and ferrite grain boundaries; (2) segregation, at the grain boundaries, of various elements dissolved in the ferrite; (3) growth of ferrite grains

(pertinent only to irreversible temper-brittleness or 'upper-nose brittleness'); (4) growth of the pre-existing carbide particles, visible under the microscope, a theory subject to the same limitations as theory (3). It is considered that none of the four offers an entirely satisfactory explanation of observed facts).

With regard to lines of further research, it is suggested that, in connexion with pressure-vessel development, investigation of the rate and extent of embrittlement in unhardened steels would be useful, and that the possibility of removing embrittlement by treatments below the temperature at which austenite forms should be explored. Determination of the cause of the embrittlement is obviously also desirable, and tests of pressure-vessel steels for toughness, before and after elevated-temperature service, should provide useful information.

Temper-Brittleness in Nickel-Chromium Steel

L. D. JAFFE: 'Temper-Brittleness of Some Fe-Ni-Cr Alloys.' *Jnl. of Metals*, 1955, vol. 7, Feb., Sect. 2 ; *Trans. Amer. Inst. Mining and Metallurgical Engineers*, 1955, vol. 203, p. 412: T.N. 255 E.

The note reports work done (in 1945–46) on ingots of varying composition prepared by re-melting S.A.E. 3135 bar stock under vacuum. Steel in 7-lb. batches was induction melted, with nickel additions, in a magnesia crucible under a pressure of 10 microns of mercury, or less, and was cast into 2-in. dia. chill moulds. The compositions of the ingots so prepared are shown in the table below:

Blanks, ½-in. square, were cut from each ingot, austenitized for one hour at 870°C., water-quenched, tempered for one hour at 595°C., and water-quenched. Half the blanks were then given an embrittling treatment of 50 hours at 455°C. and were water-quenched. A few specimens, embrittled and unembrittled, were finally heated for one hour at 580°C. and water-quenched.

Tests in a standard impact machine, at various temperatures, show that susceptibility to temper-brittleness introduced by tempering at 455°C., as measured by rise in temperature of transition from brittle to tough fracture, was reduced, but not eliminated, by lowering carbon to 0·006 per cent., manganese to less than 0·004 per cent., and nitrogen to 0·001 per cent. In another research, reported earlier, temper-brittleness was apparently eliminated by lowering carbon to 0·003 per cent., with manganese at 0·80 and nitrogen at 0·0015 per cent. (ingot D).

Elastic Constants and Thermal-Expansion Characteristics of Piping Materials

See abstract on p. 92.

Gas Turbines: Design, Materials of Construction, etc.

See abstract on p. 90.

Element %	3135 Stock	Ingot A	Ingot B	Ingot C	Ingot D
C	0·35	0·11	0·04	0·006	0·003
Si	0·22	<0·31	<0·32	<0·35	0·02
Mn	0·87	0·004	0·004	0·004	0·80
S	0·022	0·006	0·005	0·004	0·005
P	0·029	0·028	0·033	0·034	0·002
Cr	0·50	0·40	0·40	0·27	0·61
Ni	1·16	5·85	5·24	4·92	1·49
Mo	0·005	—	—	—	0·002
V	0·003	0·003	—	—	—
Al	0·020	0·057	0·021	0·009	—
Mg	—	<0·001	<0·001	<0·001	—
Sb	—	<0·01	<0·01	<0·01	—
B	0·0005	0·001	0·0027	0·0029	—
N	0·005	0·002	0·001	0·0015	0·0015
O	—	—	—	—	0·017
H	—	—	—	—	0·00006

HEAT- AND CORROSION-RESISTING MATERIALS

Gas Turbines: Design, Materials of Construction, Operation

H. ROXBEE COX (Consulting Editor): 'Gas Turbine Principles and Practice.' Published by *George Newnes, Ltd.*, London, 1955. Price 90/-.

This composite publication, sections of which are written by specialists in the respective branches of the subject, is designed to assemble, in one place, information which will give, to engineers and students, 'a broad familiarity with the latest branch of prime-mover design.' The contributors range from investigators engaged in basic research to practising designers. The scope of the individual chapters is shown below.

H. ROXBEE COX: 'Introduction', 2 pp.

R. E. WIGG: 'Gas-Turbine Cycles', 50 pp.

E. GLAISTER and A. G. SMITH: 'Thermodynamics', 62 pp.

G. B. R. FEILDEN: 'Mechanical Aspects of Gas Turbine Design', 36 pp.

A. D. S. CARTER: 'The Axial Compressor', 40 pp.

L. J. CHESHIRE: 'Centrifugal Compressors', 30 pp.

J. SHAPIRO: 'Positive Displacement Compressors', 38 pp.

L. J. CHESHIRE: 'Axial Turbines', 42 pp.

A. W. H. JAMIESON: 'The Radial Turbine', 34 pp.

C. G. CONWAY: 'Materials of Construction', 64 pp.

P. H. W. WOLFF: 'Steady Stresses in Gas Turbine Components', 36 pp.

J. R. FORSHAW: 'Vibration', 34 pp.

H. ROWLING: 'Petroleum Fuels', 18 pp.

T. F. HURLEY: 'Solid Fuels', 20 pp.

I. G. BOWEN: 'Combustion of Liquid Fuels', 16 pp.

T. F. HURLEY: 'Principles of Combustion: Solid Fuels', 20 pp.

I. G. BOWEN: 'Combustion Systems for Liquid and Gaseous Fuels', 26 pp.

T. F. HURLEY: 'Combustion Systems: Solid Fuels', 22 pp.

H. ROWLING: 'Ash Deposition: Petroleum Fuels', 16 pp.

T. F. HURLEY: 'Fuel Ash Deposition, Corrosion and Abrasion: Solid Fuels', 6 pp.

O. A. SAUNDERS and H. E. UPTON: 'Heat Exchange and Heat Exchangers', 37 pp.

R. H. SCHLOTEL: 'The Aircraft Applications', 120 pp.

C. G. CONWAY: 'Stationary Applications', 38 pp.

J. B. BUCHER: 'Marine Applications: Mercantile', 26 pp.

G. F. A. TREWBY: 'Marine Applications: Naval', 20 pp.

S. K. HAMBLING and C. S. KING: 'Transport Applications: Road Vehicles', 14 pp.

C. G. CONWAY and L. G. COPESTAKE: 'Transport Applications: Locomotives', 20 pp.

R. I. HODGE: 'Industrial Process Applications', 18 pp.

Details are given of educational facilities which are available in this field of engineering. The survey covers British and overseas Universities, and industrial establishments in the United Kingdom.

The chapter on materials of construction includes much information on the compositions, properties and uses of the nickel-containing alloys and steels which have played an important part in the development of gas turbines, primarily in the aircraft field, and also in marine and industrial applications.

Methods Used in Production of Gas-Turbine Components U.S. Practice

A. T. COLWELL: 'The Manufacture of Blades, Buckets and Vanes for Turbine Engines.'
Soc. Automotive Engineers, Preprint 440, Jan., 1955; 35 pp.

The information given in this paper, relating to practice in the plant of Thompson Products, Inc., is based on experience gained by fabrication of approximately 70 million blades and buckets for gas turbines. The scope of the paper is defined as follows: 'Methods of manufacture and the materials used for the following parts, as defined in the terminology laid down by the Society of Automotive Engineers:—

Blade: a rotating member used to compress gas.

Bucket: a part rotated by hot gas.

Vane: a stationary member used to change gas direction.'

In the Thompson plant the following production methods are mainly used, for one or more of the components considered: rough and precision forging, investment casting, Mercasting (frozen mercury), lost-plastic process (employing plastic instead of wax as the pattern material), powder metallurgy+infiltration. The outstanding features of each of the processes are reviewed, and good illustrations are given of many of the operations involved.

Tables show the nominal compositions of materials used for buckets, blades and vanes; notes are given on new materials which are in the development stage (reinforced-plastic blades, cermets, titanium), and reference is made to improvements recently introduced in machining procedures, and to fabrication problems involved in production of large paddle-type blades.

The final section of the paper gives an account of methods used, in production of the three types of components, by Rolls-Royce, Ltd., with whom Thompson Products, Inc., are in close contact. Brief reference is also made to British practice other than that of Rolls-Royce.

Influence of Cyclic Temperature Changes on Stress-Rupture of Stainless Steel

E. E. BALDWIN: 'The Stress-Rupture Strength of Type 347 Stainless Steel under Cyclic Temperature.' *Amer. Soc. Mechanical Engineers, Paper* 54-A-231, Nov.-Dec., 1954; 17 pp. + figs.

The material used in the investigation was of the following composition: carbon 0·047, silicon 0·44, manganese 1·73, sulphur 0·012, phosphorus 0·025, nickel 10·40, chromium 17·83, niobium + tantalum 0·91, per cent., iron balance. It was used in the form of 1-in. dia. centreless-ground, annealed bar stock.

The stress-rupture tests were conducted in liquid sodium (currently used as a heat-transfer medium in nuclear power plants), under constant and cyclic temperature conditions. The constant-temperature series were made at 1000°-1200°F. (538°-648°C.); in the cycled-temperature series the temperatures range was 416°-1294°F. (213°-700°C.) with cycling times from 6 to 12 hours. In addition, some short-time tensile tests were made in air, at 70°-1000°F. (20°-538°C.).

The results lead to the conclusion that mathematical expressions which have been proposed by ROBINSON (*Trans. Amer. Soc. Mech. Eng.*, 1952, vol. 74, p. 777), for calculation of the stress-rupture life of steels under cyclic-temperature conditions, give values which are only an approximation of the expected life. Deviation of the experimentally determined lives from the calculated length is considered to be due to the transient creep conditions which exist under cyclic-temperature changes, for which no allowance is made in the ROBINSON formula, nor in the simplified version suggested by MILLER. It is emphasized that the rupture life determined for the stainless steel in a given cyclic-temperature condition is true only for that condition and cannot be extrapolated with any degree of accuracy.

Chromium-Rich Chromium-Nickel Alloys: Constitutional Study

See abstract on p. 86.

Enthalpy and Specific Heat of High-Nickel Alloys and Stainless Steels

T. B. DOUGLAS and J. L. DEVER: 'Enthalpy and Specific Heat of Four Corrosion-Resistant Alloys at High Temperatures.' *Jnl. of Research, Nat. Bur. Standards*, 1955, vol. 54, Jan., pp. 15-19; R.P. 2560.

Specific-heat values, believed to be accurate, in general, to within ± 2 per cent., are reported for four types of material:

80-20 nickel-chromium alloy.

Stainless Steel (Type 347, containing chromium 18, nickel 11, niobium 1, per cent.).

Stainless Steel (Type 446, containing chromium 26 per cent.).

Monel (nickel 67, copper 30, iron 3, per cent. approx.).

Temperature °C.	Specific Heat, cal. g.$^{-1}$ deg. C^{-1}			
	80 Ni-20 Cr	Monel	Stainless Steel	
			347 Austenitic Cr-Ni	446 Straight Cr
0	0·1033	0·1009	0·1104	0·1078
25	0·1052	0·1021	0·1123	0·1105
50	0·1071	0·1033	0·1142	0·1132
100	0·1109	0·1054	0·1176	0·1185
200	0·1171	0·1097	0·1233	0·1293
300	0·1217	0·1142	0·1283	0·1401
400	0·1264	—	0·1326	0·1508
500	0·1310	—	0·1370	0·163
600	0·14	—	0·1410	0·21
700	0·1470	—	0·1448	0·1695
800	0·1515	—	0·1487	0·1631
900	0·1563	—	0·1525	0·1620

The values (see table above) were calculated from enthalpies measured by a method of which a full description is given. Discontinuities in the specific heat/temperature curves were found only in the 80-20 nickel-chromium alloy and the Type 446 stainless steel.

Effect of Temperature on Mechanical Properties of Nickel-Copper Alloys

W. D. JENKINS, T. G. DIGGES and C. R. JOHNSON: 'Effect of Temperature on the Tensile Properties of a Commercial and a High-Purity 70 per cent. Nickel/30 per cent. Copper Alloy.'
Jnl. of Research, Nat. Bur. Standards, 1955, vol. 54, Jan., pp. 21–40; R.P. 2561.

Although several important investigations have been made of the influence of temperature on the mechanical properties of Monel (70–30 nickel-copper) alloys, little information has been obtained on the influence of impurities on these properties. The work reported in this paper was specifically directed towards determination of the effect of this variable. The chemical compositions of the alloys studied are shown in the table in the next column.

In the condition as delivered (annealed bars) all the specimens had the same initial grain size and structure.

Short-time tensile testing was at temperatures ranging from 75° to 1700°F. (25° to 926°C.), and hardness tests and metallographic examination were made, at room temperature, on the fractured specimens. The results are reported in much detail, embodying curves, photographs and photomicrographs of the individual specimens in various conditions.

The conclusions are summarized as follows:

'Serrated stress-strain curves were obtained on specimens tested at temperatures ranging from 300° to 900°F. (148° to 482°C.). These serrations were more noticeable for the high-purity alloy than for the commercial alloy. Discontinuous flow also occurred in specimens of both alloys tested at temperatures above 900°F. (482°C.). The serrations were interpreted as being associated with strain-ageing and other atomic rearrangements, and the discontinuous flow at the higher temperatures as being associated with recrystallization and grain growth. Strain-ageing was also manifested in the strength/temperature relationships of both alloys; it was especially prominent in the curves for tensile and fracture strengths. Variations in composition of the two alloys markedly affected the strength properties (yield, tensile, and fracture), and reduction of area at temperatures below 1100°F. (593°C.). Above 1200°F. (648°C.) the ductilities of both alloys were nearly the same.

'The rates of work-hardening varied with the test temperatures, amount of strain, and composition of the alloys.

'The results of hardness tests made at room temperature, on specimens of both alloys fractured in tension at different temperatures, indicated the predominance of strain-ageing and work-hardening at the low range in temperature, a balance of work-hardening and recovery in the intermediate range, and the predominance of recrystallization and recovery at the higher temperatures used in the tensile tests. The hardness, at room temperature, of the fractured specimens was also dependent upon the composition of the alloy and the amount of plastic deformation.

'At temperatures below 900°F. (482°C.) the specimens of both alloys contracted locally before fracturing in a ductile manner with a rim. At temperatures above 900°F. (482°C.) specimens of both alloys deformed more uniformly, before fracturing in a relatively brittle manner without a pronounced rim. The necking and fracture characteristics were also affected by the composition of the alloys.

'The final structures and the micro-cracks produced in the specimens fractured at different temperatures varied with the test temperature, amount of plastic deformation, and composition of the alloys.'

Chemical Composition

Element %	High–Purity	Commercial
Ni	70·08	66·97
Cu	29·71	29·79
Mn	0·01	0·89
Fe	0·01	1·56
Si	0·12	0·17
C	0·017	0·15
S	0·002	0·006
Ca	(1)	0·017
Co	(2)	0·38
O_2	0·001	0·0001
N_2	0·0015	None
H_2	0·0003	0·0001

(1) Faint trace. (2) Not detected.

Elastic Constants and Thermal-Expansion Characteristics of Piping Materials

R. MICHEL: 'Elastic Constants and Coefficients of Thermal Expansion of Piping Materials Proposed for 1954 Code for Pressure Piping.'
Trans. Amer. Soc. Mechanical Engineers, 1955, vol. 77, Feb., pp. 151–7; disc., pp. 157–9.

The material contained in this report is issued under the aegis of a Committee appointed by the American Standards Association to consider revision of the Code for Pressure Piping. The new Code will contain only tabulated values, but the present report gives a detailed explanation of the sources which have been used to establish the data recommended for incorporation, and discusses methods used in arriving at the respective values proposed for publication.

The materials for which information is given include carbon-molybdenum and chromium-molybdenum steels, straight-chromium stainless steel, grey cast iron, Monel, 80–20 and 70–30 cupro-nickel, aluminium, wrought iron, copper and copper alloys.

The investigation has revealed that there are gaps in knowledge of the elastic constants of piping materials. For temperatures below 70°F. (20°C.) data are meagre for many metals and alloys used in that range, and very little published information could be found on elastic constants for wrought iron up to its maximum permissible service temperature of 750°F. (400°C.). It is, however, known that research is in

progress on this subject. Comments are also made on the need for closer standardization of methods of establishing moduli of metals at high temperatures.

Influence of Oxidation on the Surface Layers of Complex Nickel-Chromium Alloys

F. MALAMAND and G. VIDAL: 'Influence of Oxidation at High Temperatures on the Chemical Composition of the Surface Layers of a Nickel-Chromium-Titanium-Aluminium Alloy.'
Comptes Rendus, 1955, vol. 240, Jan. 10, pp. 186–8.

Two major changes occur in the surface layers of an alloy exposed to oxidizing conditions at elevated temperatures: (1) formation of a thin coating of metal oxides, (2) modification of the immediately underlying metal, as a result of selective diffusion of the elements which participate in formation of the oxides. Ultimate fracture of the material is determined primarily by the resistance of the outer layers of the metal or alloy, since a much higher stress is required to initiate fracture at the surface than that which will subsequently propagate the fracture. The effect of oxidation on the physical and mechanical properties of the surface and immediately underlying layers is therefore of major significance.

This note describes tests made to ascertain the influence of oxidation on the chemical composition of a titanium- and aluminium-containing nickel-chromium alloy, with particular reference to the effect of changes, so introduced, on the fracture-resistance of the alloy. The composition of the material studied is given as nickel 76, chromium 19·7, titanium 2·4, aluminium 1·5, per cent.

Treatment comprised solution heating for 8 hours at 1080°C., air cooling, and re-heating for 16 hours at 700°C. Specimens 10 mm. thick and 30 mm. in diameter were straightened and subsequently oxidized for 300 hours at 700°, 750°, 850° and 900°C. The oxide coatings formed were removed by cathodic pickling in a sodium/sodium-carbonate mixture, a treatment which was known to cause no change in the chemical composition of the underlying metal.

The composition of the metal specimens thus treated was determined by spectrographic examination, first at the surface, and subsequently at various depths, after removal of layer after layer by electrolytic polishing ('electro-machining'). A curve shows the percentage content of chromium, aluminium and titanium found at the surface and at depths varying down to 120 microns. These indicate that the surface layers of the oxidized material are appreciably impoverished in the strengthening elements titanium, and aluminium, and, to a lesser extent, in chromium. Restoration to the normal content of the respective elements occurs at depths varying according to the temperature of oxidation. Attention is directed to an abnormality in the titanium curve at relatively slight depths, due, it is believed, to the presence of this element in the form of a compound. Maximum reduction in metal content at the surface (by comparison with that of the bulk material) amounted to 73 per cent. for aluminium, 58 per cent. for titanium and 14 per cent. for chromium.

Passivity and Corrosion-Resisting Characteristics of Stainless Steels

P. BACHMANN: 'Passivity and Chemical Resistance of Stainless Steel.'
Schweizerische Technische Zeitsch., 1954, vol. 50, Dec. 16, pp. 809–13.

The article comprises a general discussion of the phenomenon of passivity, and a consideration of the two main theories which have been advanced to explain it: protective-film formation, and the electron-sharing theory. The constituents of stainless steels are then briefly reviewed, in relation to the contribution which they individually make to the corrosion-resistance of stainless steels. Finally, typical behaviour of stainless steels in contact with some common corrodents is described, and some illustrations are shown of stress-corrosion effects.

High-Manganese vs. 18-8 Chromium-Nickel and Straight-Chromium Stainless Steels

G. N. FLINT and L. H. TOFT: 'The Properties of a High-Manganese Austenitic Stainless Steel.' *Metallurgia*, 1955, vol. 51, Mar., pp. 125–9.

The article presents a comparison of the properties of three types of stainless steel:—

(1) containing carbon 0·08, chromium 18, manganese 10, nickel 2, per cent., and stabilized with titanium,
(2) containing carbon 0·05, chromium 17, per cent.,
(3) containing carbon 0·10, chromium 18, nickel 8 per cent., and stabilized with titanium.

The materials were used in the form of annealed sheet: corrosion tests were made on all three types, and the mechanical properties of the high-manganese steels and the 18–8 chromium-nickel type were determined. Examination included tensile tests, determination of deep-drawing properties, a study of the effect of re-heating (on structure and embrittlement), and evaluation of resistance to general corrosion (in acid and other corrodents), crevice attack (in a sodium-chloride/lactic-acid solution), atmospheric attack (in an industrial atmosphere), pitting (in ammonium-chloride/ferric-ammonium-sulphate solutions), and intergranular corrosion after welding. The results of the individual tests are recorded.

From the observations made, the following conclusions are reached:

'The deep-drawing properties of the high-manganese steel are inferior to those of the 18–8–Ti steel, due, it is believed, to the mixed austenite-ferrite structure of the manganese steel. The addition of higher percentages of manganese or nickel in this type of steel would result in a fully austenitic steel which might be expected to show ductility equal to that of the 18–8 chromium-nickel composition. The high-manganese steel does not withstand so extensive a range of corrosive media as the 18–8 chromium-nickel steel, but it does offer good resistance to many of the solutions encountered in industrial service, and would be suitable for applications in which the requirement is for an austenitic or semi-austenitic stainless steel

having corrosion-resistance approximately of the same order as that of the straight-chromium 17 per cent. type.'

Diffusion of Hydrogen through Stainless Steels

P. S. FLINT: 'The Diffusion of Hydrogen through Materials of Construction.'
General Electric Company, Knolls Atomic Power Laboratory, Report KAPL 659, Dec. 14, 1951; (de-restricted 1954); 128 pp.

The object of the experiments described was to determine the rate of diffusion of hydrogen through various materials of construction and to find means of reducing the rate of diffusion at high temperatures, chiefly in the region of 700°C.

The report is introduced by a discussion of theories of diffusion and of the factors affecting rate and intensity of diffusion of gases through solids. Apparatus and methods for study of diffusion are then described and illustrated, consideration being given to technique adopted by some other investigators as well as to methods used in the research now reported. Data obtained by the author are also correlated with those recorded by others. Measurement of rate of diffusion, made with apparatus developed by the Knolls Laboratory, covered the temperature range 100°-900°C.

The initial work was done on stainless steel of the A.I.S.I. Type 347, composition: carbon 0·08, manganese 0·4, nickel 13·3, chromium 18·4, niobium 0·8, tantalum less than 0·1, iron 68·1, per cent.: the steel was used in various surface conditions, including those produced by ageing in dry hydrogen, or by oxidizing by wet and dry treatments. The nature of the oxide coatings produced was examined in some detail.

The tests were extended to examination of the permeability, to hydrogen, of other types of steel and alloys: low-carbon steel, straight 18-8 chromium-nickel steel, and molybdenum- and titanium-stabilized 18-8 steels, two types of 13 per cent. chromium steel, and an alloy containing chromium 7, nickel 44, per cent., balance iron.

Behaviour characteristic of the respective materials is recorded in full, and the following conclusions are drawn:

It was found that the rate of diffusion for Type 347 stainless steel can be represented, for the temperature range 200°-600°C., by the equation.

$$\log S = 2{\cdot}19 - \frac{3{\cdot}18 \times 10^3}{T}$$

S is the diffusion constant, T is expressed in cc (STP)/cm²/hr./mm. at 760 mm. of hydrogen pressure, and T is the absolute temperature. Above 600 °C. the rate of diffusion is progressively greater than is indicated by the equation: at 800°C. the rate is 2·7 times the calculated value. In examination of the stainless steels variations as great as 50 per cent. were found, under identical conditions, for the diffusion rate in different specimens of any one type of steel. The small variations of composition in the austenitic nickel-chromium steels studied (including the addition of stabilizers) appeared to have little effect on the rate of diffusion.

Nitriding of the surface of the steels had little or no effect on their permeability to hydrogen; chromium plating much reduced permeability, but the plate cracked off during thermal cycling in hydrogen. Calorized stainless steel showed a hydrogen-permeability rate 100-fold lower than that of uncoated metal. Ceramic coatings, of compositions specially selected to ensure coefficients of expansion comparable with those of stainless steel, also markedly reduced rate of hydrogen diffusion, as did a spinel coating produced by treating the niobium-stabilized (Type 347) stainless steel with wet hydrogen at temperatures up to 1000°C.

Rate of diffusion of hydrogen resulting from reaction of stainless steel with atmospheric moisture at elevated temperatures was also studied, and some correlated data on the hydrogen permeabilities of a number of common metals and alloys, and the solubility of hydrogen in these metals, are included in the report.

Production of Stainless-Steel Tankers

'Stainless-Steel Tankers. Production Methods.'
Welding and Metal Fabrication, 1955, vol. 23, Mar., pp. 80-1.

This short article gives an illustrated description of some of the production methods employed at the works of Taylor, Reid and Company, Ltd., Preston, Lancashire, who make large numbers of welded stainless-steel road tankers and other containers for the chemical, dairy and other industries. Reference is made to some specialized fittings developed by Taylor, Reid in connexion with this work, e.g., a sliding manway comprising an oval type of lid which is tightened up against the inside of a tank in such a way as to cover the manhole.

Electrolytic Salt-Bath Descaling of Nickel-Chromium Steels

T. J. NOLAN and G. E. ROWAN: 'Electrolytic Salt Baths Descale Hot- and Cold-Rolled Stainless Strip.'
Iron Age, 1955, vol. 175, Mar. 3, pp. 119-21.

The writers describe a continuous plant which is in operation in the stainless-steel mill of Atlas Steels, Ltd., Welland, Ontario, where strip of both austenitic nickel-chromium and straight-chromium steels is produced. The procedure consists in passing the strip, after annealing and quenching, into the first salt bath, in which the scale is oxidized, and thence into a second bath in which the oxidized scale is dissolved. After the second treatment the work passes into three acid-pickle tanks: (1) hot sulphuric acid, concentration unspecified, (2) dilute sulphuric, in which electrolytic pickling is employed, and (3) a tank containing a nitric-acid solution in which a small amount of hydrofluoric acid is present. The layout of the plant and its operation are described and illustrated.

Stress Corrosion of Stainless Steels

J. J. HEGER: 'Stress Corrosion of Stainless Steels.' *Metal Progress*, 1955, vol. 67, Mar., pp. 109–16.

Four types of corrosion have been encountered in stainless steels:

General corrosion, involving complete breakdown of the protective film.

Intergranular corrosion, caused by breakdown of the protective film at grain boundaries (usually depleted in chromium).

Pitting corrosion, resulting from localized breakdown of the film.

Stress corrosion, also resulting from localized breakdown of the film, accelerated by stress, and giving rise to cracking.

The fourth type, stress corrosion, is the subject of this review.

Corroding environments in which stress corrosion has been observed in service are listed below:

Sulphite liquor	Crude petroleum
Ethyl chloride	Marine atmosphere
Steam at 950°F. (510°C.)	Orange juice
City water	Inhibited calcium chloride
Humid air at 185°F (85°C.)	Sulphurous acid
Dye liquor	Sulphuric acid
Brine	Boiling sodium hydroxide

Brief notes are given on specific failures occurring in some of the above corrodents.

The paper is mainly concerned with studies carried out in the laboratories of the U.S. Steel Corporation, over a six-year period. Observations were made on stress-corrosion failures which had occurred in three conditions:

(1) In environments definitely known to contain chlorides or halides.

(2) In environments in which the presence of chlorides or halides was suspected.

(3) In environments containing no chlorides or halides.

Typical examples of service failures of each kind are illustrated, and the nature of the attack is discussed.

Consideration of the incidence of stress-corrosion cracking in the respective conditions led to inception of laboratory tests designed to study the environments involved and the degree of the stress required to cause cracking. Corrodents found to cause such failure were: ammonium, calcium, cobalt, lithium, magnesium, mercuric, sodium, and zinc chlorides, and moist hydrogen sulphide. It is thus evident that chlorides are highly conducive to this type of attack, but the fact that moist hydrogen sulphide is also deleterious is confirmed by an investigation of stress-corrosion cracking in the presence of sulphur compounds carried out by REES in 1947. The degree of stress required to cause cracking varies with the prior treatment of the material and with the nature of the corrosive medium in which the steel is exposed.

With regard to preventive measures, it is thus obvious that reduction of susceptibility may be effected by selection of alloy compositions peculiarly resistant to specific corroding environments, and by attention to design, in order to minimize stress. Stress-relief heat-treatment, relief of stress by peening, admixture of inhibiting agents with the corrodents, and cathodic protection are other means by which susceptibility may be minimized.

Nickel Alloys for Handling Aqueous Hydrofluoric Acid

M. SCHUSSLER: 'Metal Materials for Handling Aqueous Hydrofluoric Acid.' *Reprint from Industrial and Engineering Chemistry*, 1955, vol. 47, Jan., pp. 133–9. Issued by International Nickel Co., Inc., 1955; 8 pp.

See abstract in *Nickel Bulletin*, 1955, vol. 28, No. 3, p. 54.

Stainless Steel in the Dairy Industry

'Bulk Collection of Farm Milk.' *Times Rev. Industry*, 1955, Feb., p. 32.

A scheme now under trial in the dairy industry will, if generally adopted, call for large-scale use of stainless steel and refrigerating equipment. The essential features of the new method (which is already in operation in the U.S.A., Australia, and New Zealand) comprises the installation, on the farms, of refrigerated bulk tanks, from which the milk is picked up daily or at other stated intervals, by an insulated road tanker. The milk is pumped direct to the tanker through a pipe line. At the receiving dairy it is pumped into bulk holding tanks, heat-treated, and bottled. Where completely mechanical methods of milking and handling are employed, and the bulk storage and collection procedure is followed, the first time the milk is moved by the human hand is when the roundsman brings it from his vehicle to the customer.

Apart from the obvious advantages of minimizing handling, bulk collection ensures the reception of milk of improved quality: it arrives at its destination at a temperature of about 40°F., which is ideal from the dairy point of view. Records kept by a dairy which received both bulk and churn milk (the former from a long distance) show that the bulk-collected milk has proved to have superior keeping quality.

This article describes some of the equipment and methods used, and discusses the pros and cons of wider adoption of such procedure.

Stainless Steel in the Wine Industry

K. WATSON: 'Generous Wine.' *Canad. Chemical Processing*, 1955, vol. 33, Jan., pp. 28, 30, 32.

This short article describes activities in the plant of Canada's oldest working winery, Barnes Wines,

Ltd., of St. Catherines, Ontario. The sequence of operations is briefly described (fermentation, sedimentation and ageing, filtration, etc.), and particular reference is made to the baking step which is carried out in production of certain types of port and sherry. The purpose of the baking is to impart a distinctive flavour and bouquet to the wine, and the treatment consists in heating at 110°–120°F. (45°–50°C.) for 7–10 days.

This treatment was formerly carried out in a 6,000-gallon wooden cask, but during processing the cask became spongy, subsequent cleaning was difficult, and there was a tendency to accumulation of bacteria. Following tests which showed that stainless steel would have no adverse effect on the wine (nor would the wine attack the steel), it was decided to replace the wooden cask by one of nickel-chromium stainless steel, and this major innovation has proved highly successful. The wine is passed through stainless-steel heat exchangers to the baking tank, which is used as a holding unit. The final operation, prior to bottling, is that of bulk pasteurization, which is now applied to almost all the wines processed, and for the pasteurizing vessels stainless steel has also proved outstandingly suitable.

Nickel-containing Materials in Contact with Agricultural Chemicals

C. F. SCHREIBER: 'Corrosion of Aircraft Structural Materials by Agricultural Chemicals. 2. Effect of Insecticides, Herbicides, Fungicides and Fertilizers.' *Corrosion*, 1955, vol. 11, Mar., pp. 33–44.

Report of work carried out at the Texas Engineering Experiment Station, U.S.A. The results of the individual tests are reported in extenso. The conclusions drawn were summarized in *Corrosion Technology*, 1954, vol. 1, Oct., p. 295; see *Nickel Bulletin*, 1954, vol. 27, No. 12, p. 236.

Welding of Some Wrought High-Alloy Materials

R. P. CULBERTSON: 'Weldability of Wrought High-Alloy Materials.' *Welding Jnl.*, 1955, vol. 34, Mar., pp. 220–30.

This is essentially a reference paper, giving practical information on conditions optimum for welding typical high-alloy materials, by the submerged-arc, inert-gas-shielded-arc, and metallic-arc methods. The types of alloy for which recommendations are made are indicated in the table below.

Table I

	Nickel–Molybdenum Alloy	Nickel–Molybdenum–Chromium Alloy	Cobalt–Chromium–Nickel–Tungsten Alloy	Alloy N–155
C	0·05 max.	0·15 max.	0·15 max.	—
Si	1·00 max.	1·00 max.	1·00 max.	—
Mn	—	1·00 max.	1·0–2·0	—
Ni	Bal.	Bal.	9·0–11·0	19·0–21·0
Cr	1·00 max.	15·5–17·5	19·0–21·0	20·0–22·5
Fe	4·0–7·0	4·5–7·0	3·0 max.	Bal.
Co	—	—	Bal.	18·5–21·0
Mo	26–30	16–18	—	2·5–3·5
Nb–Ta	—	—	—	0·75–1·25

The properties of these alloys are broadly similar to those of austenitic steels, but the alloys exhibit individual characteristics which require consideration during fabrication and welding. The precautions required are discussed in relation to each material, and features of common interest (e.g., surface preparation, joint design, edge preparation, and jigging and fixing) are reviewed. Much detailed information is given, with regard to all aspects of welding technique, and the influence of variables in welding procedure, on the properties of the joints (at normal and elevated temperatures), is demonstrated. The paper is very well illustrated.

The following general conditions are indicated as essential for production of welded joints in the materials discussed:

Existence of minimum weld constraint.
Maintenance of the base material at approximately room temperature.
Preservation of good alignment of joints.
Use of stringer beads.

Welding of Austenitic Stainless Steel to Ensure Freedom from Sigma-Phase Formation

R. M. CURRAN and A. W. RANKIN: 'Welding Type 347 Stainless Steel for 1100°F. Turbine Operation.' *Welding Jnl.*, 1955, vol. 34, Mar., pp. 205–13.

The report is an outcome of experience in use of

welded austenitic steel shells, casings, heads, piping and other components in large steam turbines operated at the 1050°F. (565°C.) level, and is based on research arising from the need to improve the high-temperature behaviour of the welded joints, with particular reference to prevention of sigma formation.

Chemical Composition of Deposited Weld Metal

	%
Carbon	0·07–0·10
Silicon, max.	0·50
Manganese	0·50–2·50
Sulphur, max.	0·025
Phosphorus, max.	0·025
Chromium	18·5 –20·5
Nickel	9·0 –10·5
Niobium	0·60–0·90
Silicon/Carbon ratio ..	5/1
Ferrite content (calculated from Cr-Ni equivalents according to the Schaeffler diagram)	1–4

The ultimate aim of the work was the development of an electrode and welding procedure giving niobium-stabilized austenitic welds which would be essentially immune from sigma-phase embrittlement in service at 1100°F. (595°C.) and higher temperature.

On the basis of the laboratory tests and service experience recorded the following conclusions are drawn: 'Sound welds can be produced in Type 347 stainless steel by using an electrode having a ferrite content in the range 1–4 per cent., and giving a deposit within the limits shown in the table in this column.

The use of a post-weld heat-treatment at 1925°F. (1050°C.), on welds made with such electrodes, results in an appreciable increase in their resistance to embrittlement on long-time exposure to elevated temperatures. Highly restrained austenitic weldments can be heat-treated successfully in the range 1900°–2000°F. (1035°–1095°C.), provided that a rapid rate of heating is used.

The long-time rupture strength, at high temperatures, of low-ferrite welds heat-treated at 1925°F. (1050°C.) is comparable with the corresponding long-time high-temperature strength of the Type 347 base metal.'

The authors emphasize that this report deals only with one aspect of a very complex subject, and that even in this case the validity of the conclusions drawn can be established only after years of service at the 1100°F. (595°C.) and higher levels. In particular, also, they urge the need for further research on the causes of cracking during post-weld treatment and in service.

Nickel-base Alloys for Brazing Stainless Steels

C. V. FOERSTER and R. C. KOPITUK: 'Joints Brazed with New Nickel-base Alloys Exhibit Good Properties.' *Iron Age*, 1955, vol. 175, Feb. 24, pp. 79–82.

This article deals with the use of a series of nickel-base alloys developed for brazing of stainless steels and high-temperature alloys. Joints made with them are claimed to have good mechanical strength at elevated temperatures, together with high resistance to corrosion and oxidation.

The compositions of the brazing alloys discussed are given below:

The alloys are made as rod, powder, wire, strip, and paste: technique employed for using them in the respective forms is considered. These brazing materials are stated to perform satisfactorily with joint designs normally used for conventional brazing alloys. The amount of alloy used and the temperature of brazing must be regulated according to the thickness of the parent material, in order to prevent excessive alloying of the base with the brazing alloy, which weakens the joint. The importance of ensuring completely clean surfaces for brazing is emphasized: recommended procedure is detailed.

Brazing Materials

Alloy No.	Ni %	Si %	B %	Cr %	Fe %	Other Elements %
50	93·25	3·50	2·25	—	—	1·0
52	91·25	4·50	3·25	—	—	1·0
53	82·10	4·50	2·90	7·0	3·0	0·50
56	71·25	4·0	3·75	16·0	4·0	1·0

Hard Facing with Nickel-base Alloys

H. S. MILLER: 'Practical Hard Facing with Fused Self-Fluxing Metallized Coatings.' *Welding Jnl.*, 1955, vol. 34, Mar., pp. 214–19.

This paper deals with the technique of 'Spraywelding', a process which comprises a combination of spraying and welding. Four stages are involved: preparation of the surface of the basis material, spraying of the facing deposit, fusing of the deposit, and finishing.

Three alloys which are particularly important for

Colmonoy Alloy No.	Nickel %	Chromium %	Boron %	Iron %	Hardness Rockwell C
6	70	16	4	bal.	60
5	76	13	3	bal.	50
4	80	11	2½	bal.	40

Spraywelding are of nickel-chromium base and contain substantial quantities of boron: typical compositions are shown above:

Deposits of such alloys give exceptionally good resistance to wear and corrosion, over an extensive range of temperature. Stainless steels, of both austenitic nickel-chromium and straight-chromium types, K Monel (precipitation-hardening nickel-copper alloy), and Inconel (nickel-chromium-iron alloy) are also used for Spraywelding, in applications requiring resistance to various types of corrosion and wear.

I. *Preparation of the Surface*

The parts are undercut by the amount of the overlay required, cleaned with a solvent, or degreased, and grit-blasted. The grit-blasting step is important in securing satisfactory results and this operation should be meticulously performed, especially in the corners of the undercut. The area which is not to be faced is masked with blasting tape. Where grit-blasting facilities are not available fine threading may be used, but the blasting treatment is preferred.

II. *Spraying of the Deposit*

There are two principal methods of spraying the self-fluxing alloys used for Spraywelding: (1) by a wire gun, or (2) by a powder gun. Typical units of both varieties are described, and reference is made to a new type of powder gun which simultaneously sprays and fuses the powder.

III. *Fusing the Deposit*

Three methods may be used: induction heating, heating in a controlled-atmosphere furnace, or heating by torch or open flame. Experience with all three procedures is discussed, and their respective spheres of usefulness are indicated. Specific conditions for use in Spraywelding with nickel-chromium-boron alloys of the three compositions are recommended, and much practical advice is given as to general conditions required for successful fusing.

IV. *Finishing*

Recommendations are made with regard to machining and grinding. Provided that correct conditions are maintained, the nickel-chromium-boron alloys are easily machined: for coatings of No. 6 alloy finish grinding is recommended, after rough-machining to within 0·015 in. of finish size. Details of procedure are given.

Nickel-Chromium-Boron Facing of Pump Plungers

'Hard Facing Alloy Extends Hydraulic Pump Plunger Life.' *Iron Age*, 1955, vol. 175, Mar. 3, pp. 122-3.

This article quotes a typical case of the increased life which can be obtained by hard-surfacing with nickel-chromium-boron alloy of the Colmonoy No. 6 type: see previous abstract.

In the plant of Scovill Manufacturing Company at Waterbury, Conn., facing of the hydraulic pump plungers of a billet-extrusion press has markedly reduced maintenance costs. The low friction coefficient of the fusion-welded alloy surface has virtually eliminated wear of the plunger, and the useful life of the metallic packing used to seal the plungers has been more than tripled. Prior to the use of the hard facing, plungers of air-hardening tool steel or of chromium-plated carbon steel rapidly scratched in service, and the life of the packing used with them was about 86 days, which was achieved only by intermediate addition of new packing. New plungers of carbon steel, spray-welded with the nickel-chromium-boron alloy, operated for 329 days without the need for addition to the original packing. When examined at that stage the packing showed no sign of wear and no significant scratching was visible on the plunger.

Determination of Selenium in Stainless Steels

W. J. BOYER and O. H. FRITZSCHE: 'Turbidimetric Method for the Determination of Selenium in Stainless Steel.'

Analytical Chemistry, 1955, vol. 27, Feb., p. 310.

Abstract of paper to Pittsburgh Conference on Analytical Chemistry, Feb.-Mar., 1955.

A 0·10-gram sample is dissolved in a nitric-hydrochloric acid mixture, followed by perchloric-acid oxidation to eliminate the carbides present. After oxidation, a dilute hydrochloric-acid solution is added and the selenium is reduced with stannous chloride. A photometric measurement of the turbidity of the solution, before and after filtration, yields readings proportional to the amount of selenium present in the sample.

Analysis of Thin Films of Nickel and Stainless Steel

See abstract on p. 84.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks*.

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